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Underground Temperature Survey in and around the Landslide Area −1−

(A New Investigation Method of Underground Water)

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Abstract

It has been clarified by the existing investigated results that the underground water was existent as the vein-stream in and around the landslide area. Therefore, it was very difficult to obtain the informations concerned with location of the vein-stream of underground water by using various kinds of tracer methods. As it would be preferable to assume the location of the vein-stream before carring out the existing tracer methods and conduct the survey, the author tried the underground temperature survey which had been utilized at the hot-spring in order to presume the location of the underground water vein-stream. Excellent results were obtained by this survey method.

1. Introduction

It is well known that many landslides occur in a region of particular geological conditions. But landslides do not occur only from the reason that the region has particular geological conditions. In a word, particular geological conditions are the basic factor concerned with the occurrence of the landslides, but landslides do not occur only from this basic factor. That is, immediate occasions are necessary to cause landslides. There are many kinds of natural and artificial factors which constitute such immediate occasions. In either case, it goes without saying that the underground water existing in and around the landslide area play a very important role as a trigger of the occurrence of landslides. Accordingly, the informations related to the underground water in and around the landslide area are required in the event of preventive measures to be considered.

The matter which must be clarified about the underground water in the beginning, is the route of supply of underground water to the landslide area. It is necessary to clarify the routes and kinds of the underground water and to obtain informations concerning the effect on the landslide movement. When these points are clarified, the degree of contribution of the underground water to the landslide movement can be estimated, and the appropriateness of preventive measures based on informations concerned with the underground water can be judged. If this work is judged to be pertinent, we can discuss the most effective and reasonable method for conduction of the underground water, and important data will be offered for planning landslide preventive measures.

In this way, the investigations related to the underground water occupy an important position in landslide investigations. Nevertheless, it seems that the tracer method of the underground water conducted at present has imperfect points. Thus, the author inquired into the imperfect points from the existing condition of underground water in and around the landslide area. As a result he realized the necessity of carrying out a new underground water investigation method before conducting the existing tracer method.

At this time, the necessity of this new method is described and a practical example of this method is introduced simply.

2. The Existing Condition of Underground Water in and around the Landslide Area

Generally, sources of supply of underground water to the landslide area are from permeance of rain-fall, snow-fall and thaw in catching area including the landslide area; inundation from springs and ponds in the landslide area; and leakage of water from flumes, overflows, mountain torrents and rivers. And underground water flowing into the landslide area from afar exists to a considerable degree regardless of the catching area.

In what form is the underground water supplied to the landslide area, flowing in and out of area? In our experiences, it was found that the underground water is flowing out as a veinlike stream from a cutting slope or a head scarp of the landslide area.

From the results of the underground water tracer investigations conducted by the authors and other institutes, the velocity of the underground water in and around the landslide area is 10^{0}–10^{-2} cm/sec. (Table–1) Calculating the coefficeient of permeability on the basis of these values, those values are equal to 10^{1}–10^{-1} cm/sec. If the underground water layer with such velocities exists in and around the landslide area, the nature of the soil, presumed from those velocities will be clean sand or clean

Table 1. Velocity of underground water in the spot and coefficient of permeability.

Name of landslide area	Prefecture name	Observed velocity u (cm/sec)	Coefficient of permeability in the spot k (cm/sec)
Matsunoyama	Niigata	0.1 –0.42	0.55– 2.33
Miza	Toyama	0.63	4.85
Miza	〃	3.40	7.95
Kushibayashi	Shiga	0.2 –2.2	1.25–13.75
Kamioogi	Shiga	10^{-2}–10^{0}	0.09– 8.77
Kamenose	Oosaka	0.10–0.18	0.13– 0.24
Kamenose	〃	0.26–2.64	0.28– 2.82
Mikage	Hyogo	0.36–0.48	1.8 – 2.4
Mikage	〃	1.16–2.08	8.79–15.76
Kebioka	〃	0.43	1.95
Kebioka	〃	0.17–0.62	0.31– 1.15
Kita-Soo	〃	0.01–0.04	0.03– 0.13
Tando	〃	0.19–0.30	1.90– 3.00
Kusugami	Kochi	0.22–0.28	0.37– 0.48
Kawai	〃	0.39	0.33
Engyoji	〃	0.11	0.22
Nishikawa	〃	0.33–0.92	0.42– 1.15

k was obtained by P. P. Klimentob'method

Table 2. Permeability and drainage characteristics of soils.

Coefficient of permeability k in cm/sec (log scale)

10^{2} 10^{1} 10^{0} 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8}

Drainage		Good	Poor	Practically Impervious
Soil types	Clean grave	Clean sands, Clean sand and gravel mixtures	Very fine sands, organic and inorganic silts, mixtures of sand silt and clay, glacial till, stratified clay deposits, etc. "Impervious" soils modified by effects of vegetation and weathering	"Impervious" soils, homogeneous clays below zone of weathering

sand and gravel mixtures. (Table–2) When such soil exists in and around the landslide area, the underground water layer having the above-mentioned velocities can exist. But in actuality it should not be considered that such soil is distributed throughout the area in and around the landslide. Observing the profiles of bore holes which are utilized as detected points or throwing points, the structure of stratum consists of mudstone, shale, sandstone, clay, etc.. Obtaining the coefficeint of permeability of those stratums in a laboratory, the values show to be very small, 10^{-4}–10^{-6} cm/sec in many cases. For example, in the case of the Kamioogi landslide area in Shiga Prefecture, the coefficient of permeability on the spot is 10^{1}–10^{-1} cm/sec, but in a laboratory it shows very small values such as 10^{-4}–10^{-7} cm/sec.

Eventually there is a very large difference between the coefficient of permeability on the spot and that in a laboratory. If the landslide preventive work based on the underground water is conducted on the basis of the values obtained in a laboratory, it would appear that the underground water existing in the landslide area is drained off only with difficulty. But on the other hand if the result on the spot is adopted in the work, it appears that the underground water existing in and around the landslide area is drained off easily by drainage borings or water collecting wells.

In actuality, it can be observed that the underground water existing in and around the landslide area is excluded very effectively from drainage borings or water collecting wells. This fact shows that the underground water in and around the landslide area flows in not only through the stratum having a little permeability but also the stratum having a large permeability which exists in some part of the former stratum. And if measures for drainage of underground water are conducted in the stratum having a large permeability, the underground water can be excluded very effectively.

Eventually as being often caught in boring cores in the landslide area, there are places with large circulation in and around the landslide area, and it is considered that such places are all connected togather and thus make an underground water vein-stream, and further, that the underground water flowing in the vein-stream, and further, that the underground water flowing in the vein-stream has a large velocity as shown in Table–1.

Next are references to reports giving substance to the above conception.

Matsubayashi and Mochizuki (1967, 1969 and 1970) [1),2),3)] described the following matter on the basis of the results of underground water investigations in the Chausuyama landslide area in Nagano Prefecture: "The underground water at the upper section in the Chausuyama landslide area exists in numerous comparative shallow zones in a rainy season. But the underground water in shallow zone does not overspread uniformly horizontaly, but flows among *mizumichi* (place having a large permeability in stratum). And the underground water which is stocked as cistern-like in lenticular sand layer existing here and there, distributes complicatedly. Accordingly even if the aquifers exist in neighboring areas and to similar depth, the aquifers are not always mutually connected directly. On the other hand, from the results in a dry season, it seems clear that the underground water existing in the shallow zone decreased and the underground water flowing in the deep zone-like vein-stream becomes main, and this point is confirmed by the concentration curve of the tracer method. Because the underground water exists as vein-streams, the tracer can not be detected systematically, and the tracer can not be detected from even the hole contiguous to the detected hole of the tracer. The velocity obtained from the underground water is 1.7×10^{-1} cm/sec. This velocity shows clearly that the underground water flows through weak parts in the stratum."

Tanaka (1966)[4] described the following matter on the basis of the investigation results of underground water in the Matsunoyama landslide area in Niigata Prefecture: "The flowing channels of underground water are connected with a chain from the upper section of Usagiguchi region to the lower section of Hikaruma region. The velocity of the underground water is 10^{-1} cm/sec. From such a value of velocity, it is considered that the underground water has its flowing channel among the faults line or in weak parts in the stratum."

Oohira, Kishimoto and Sugano (1966)[5),6] described the following matter on the basis of the investigated results of underground water in the Shimoyunoiri, Gouhara landslide areas in Nagano Prefecture and in the Shimodaikoku, Chiai landslide areas in Shimane Prefecture: "It is considered that the underground water has a *mizumichi*. And by discussing the observed results of underground water level, the *mizumichi* is often changed or is opened or closed by a heavy rain."

Yamaguchi, Takada and Takeuchi observed a distinct underground water vein-stream by the underground water tracer method using NaCl and fluorescene soda in the Kebioka landslide area (1966)[7], the Mikage landslide area (1967)[8] in Hyogo Prefecture, and the Hitoji landslide area in Nara Prefecture (1968)[9]. About the closing phenomena of the underground water vein-stream pointed out by Oohira etc., Yamaguchi, Takada and Takeuchi found out the same phenomena at the Kushibayashi landslide area in Shiga Prefecture (1969)[10]. This case, the cause is not a heavy rain, but some artificial factor in dry season. From this fact they considered that the closing phenomena of the underground water vein-stream was possible and there was possibility for landslide occurrence originating from that phenomena.

Synthesizing these reports, it is suggested strongly that the underground water connecting with the landslide activity exists as vein-stream form rather than as stratiform. This conjecture may not be applied to all landslide areas but, in the case of interpreting the phenomena on the spot, this conjecture is most reasonable.

In the Kushibayashi landslide area, in the case of a part of the underground water vein-stream closed by some cause, confined water is gathered behind that part and for this cause the pore water pressure increases and the resistivity against the sliding force of the landslide mass decrease. It is sufficiently considered that a partial landslide activity occurrs from this phenomena and that this activity spreads in all areas of this landslide area, which is the critical condition for landslide movement and thus a large scale landslide movement can occur. It is possible that a partial landslide activity develops into a large scale landslide movement from the hydrostatic pressure in the underground water vein-stream, which is caused by the supply of a large quantity of water. (Fig. 1) Accordingly, if a partial section of abnormal condition of under-

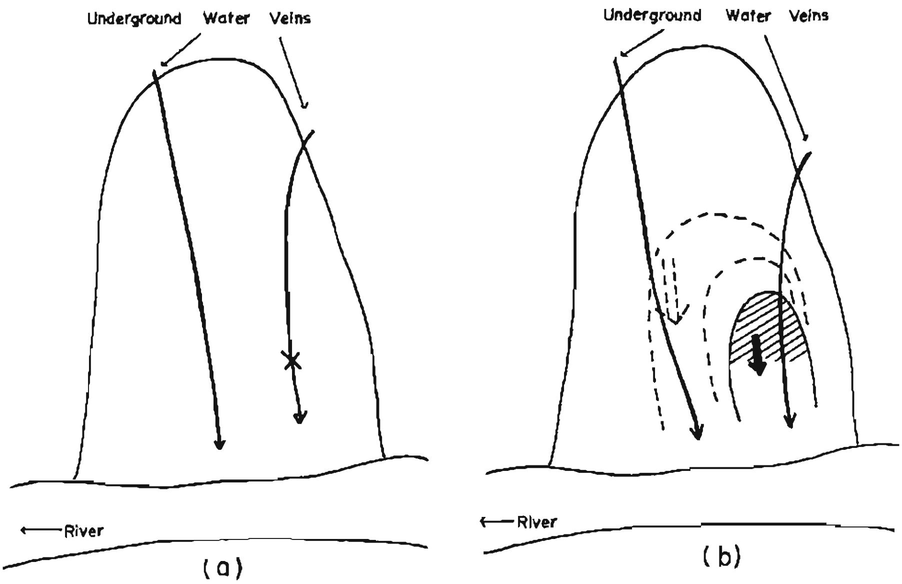

Fig. 1. (a) A model case of closing condition of underground water vein.
(b) Ocurring condition of partial landslide movement.

ground water is found out and the water gathering in this section is excluded in a hurry, the partial landslide activity caused by abnormal underground water can be prevented and a large scale landslide movement can be prevented too. For this prevented and a large scale landslide movement can be prevented too. For this purpose it is necessary that the underground water vein-stream be found out in advance in order to conduct the proper measures for the drainage of underground water.

3. Imperfect Points of the Existing Underground Water Investigation by Tracer Method

It is considered that the underground water related to the landslide movement exists as vein-stream form rather than as stratiform. Moreover, if this vein-stream results in an abnormal condition from some cause and thus produceses possibility of development into a large scale landslide movement, it is important that the underground water vein-stream be found out. Therefore, reconsidering the existing underground water investigation by tracer method, it becomes clear that this method has many difficult points when obtaining the informations related to the flowing channel of underground water vein-stream.

Every kind of underground water investigation methods at present are conducted for obtaining the informations related to the flowing channel and the block analysis of underground water, but in every methods, it is necessary to sample the water directly from boring holes, spring points, wells or ponds. This fact means that the accuracy of informations obtained by above-mentioned method is under the control of the quantity of the sampling points. Accordingly it is difficult to expect accurate informations related to underground water in the landslide area having an insufficient number of sampling points.

For example, we will make the assumption that there is a small landslide area having three boring holes and one spring point as shown in Fig. 2. In this figure B_1 is a

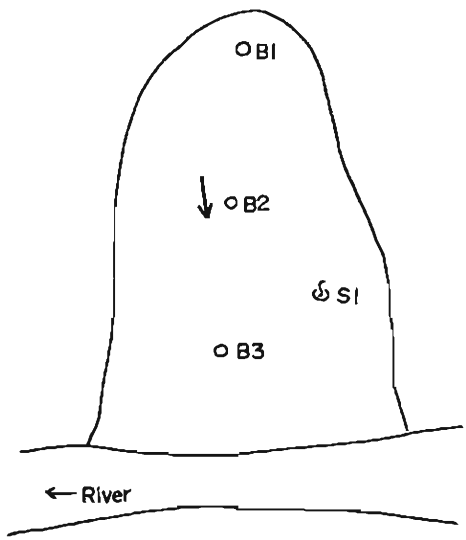

Fig. 2. Model landslide area for underground water investigation.

throwing point of tracer and B_2 and B_3, S_1 are detecting points of it. Here a suitable chemical was thrown into the B_1 boring hole with water as tracer and we observed each detecting point in order to catch a variation of the quality of water causing the thrown tracer. From the result we caught a variation of the quality of water at the B_2 and B_3 boring holes but did not catch such at the S_1 spring point.

In the case of such an assumption the result of this investigation may be understood as follows in the usual interpretation:

The underground water flowing at B_1 flows downward by way of B_2 and B_3. But we must consider at this point that the underground water vein-stream does not exist at the point of B_1. In other words the tracer thrown into B_1 may flow certainly downward by way of B_2 and B_3, however it can not be affirmed that the underground water vein-stream consists of such a channel. It can be only affirmed that the tracer thrown into B_1 with water, permeates into the landslide soil mass and reaches B_2 and B_3. Accordingly from the result of the tracer method, it is clarified that B_1, B_2

and B_3 connect with each another, however, it can not be affirmed that the underground water vein-stream exists at that place. It is rarely the case that the vein-stream exists practically in agreement with the presumed channel. When the vein-stream does not flow through the throwing point, the tracer thrown into B_1 may have

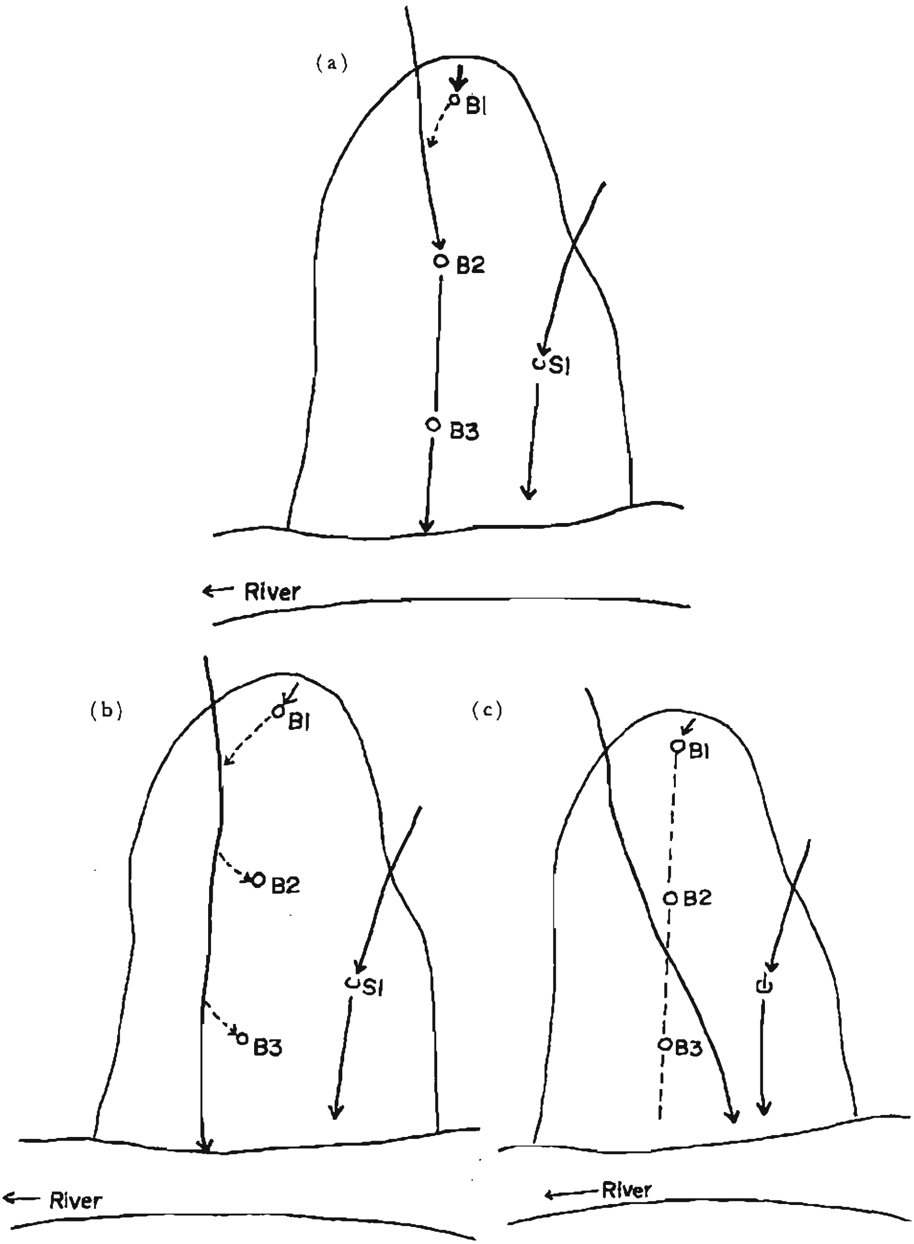

Fig. 3. (a)-(c) Relation between underground water veins and underground water investigations by tracer method.
B_1... throwing point, B_2, B_3 and S_1... detecting points.

flowed into the vein-stream flowing beside the throwing point B_1, and the tracer might be detected at B_2 and B_3. (Fig. 3(a)) Or it can conjectured that as a large quantity of water is injected into the throwing point when throwing the tracer, the water deviates from a main stream of the vein-stream and reaches the detecting points B_2 and B_3 (Fig. 3(b)) Or again, as shown in Fig. 3(c), regardless of any existing vein-stream at all, it is considered that the relation between B_1, B_2 and B_3 only might be obtained. In such a small scale landslide area, when conducting the underground water investigation by tracer method without presuming the existing position of underground water vein-stream, much conjecturing can be done. It is not so easy to decide the channel of the vein-stream which is flowing down. And much less easy when presuming the existing position of the vein-stream in a large scale landslide area having extensive and complicated configuration. It is, needless to say, attended with very great difficulties.

If the tracer thrown into B_1 does not reach the detecting point S_1, as shown in Fig. 3, accordingly the throwing point B_1 has no connection with the detecting point S_1. In other words, it is considered that the water flowing out at the spring point S_1 flows into the landslide area by way of another channel. In order to catch the other vein-stream flowing out of the spring when using the existing tracer method, the throwing point of the tracer is set up at a suitable place, and the investigation similar to the former must be repeated again. Moreover there is no guarantee that the tracer thrown into the throwing point will reach the spring point S_1. Accordingly it is very difficult to find the vein-stream flowing out of the spring point S_1. Many investigating days and expense will be spent to find out the channel of the other vein-stream.

From the considerations mentioned above it would be dangerous in large measure to discuss the channels of vein-stream in and around the landslide area on the basis of the results of the existing tracer method using a small number of sampling points. If underground water drainage, as a landslide preventive measure, is carried out on the basis of the results of the existing tracer method, we can not firmly rely on the effects of these measures.

4. The New Investigation Method of Underground Water

4.1. Necessity of the new investigation method of underground water

It must be avoided as much as possible that the landslide preventive works related to underground water are carried out under the above-mentioned conditions. So it is necessary that accurate information about the channel of vein-streams are obtained in order to heighten the effect of the preventive measures.

The existing underground water tracer method requires much time and expense, so the informations thus obtained are precious. So in order to put such precious informations to practical use, the channels of vein-stream are presumed in advance and the importance of each vein-stream having an effect on landslide activity is discussed before conducting the tracer method. And the tracer method should be conducted for the confirmation of the main vein-stream important for the landslide activity.

From the above-mentioned considerations, the author discusses wheather or not the underground temperature survey, which is effective as a hot-spring survey method, can be adapted as one of the methods to presume the position of vein-streams in and

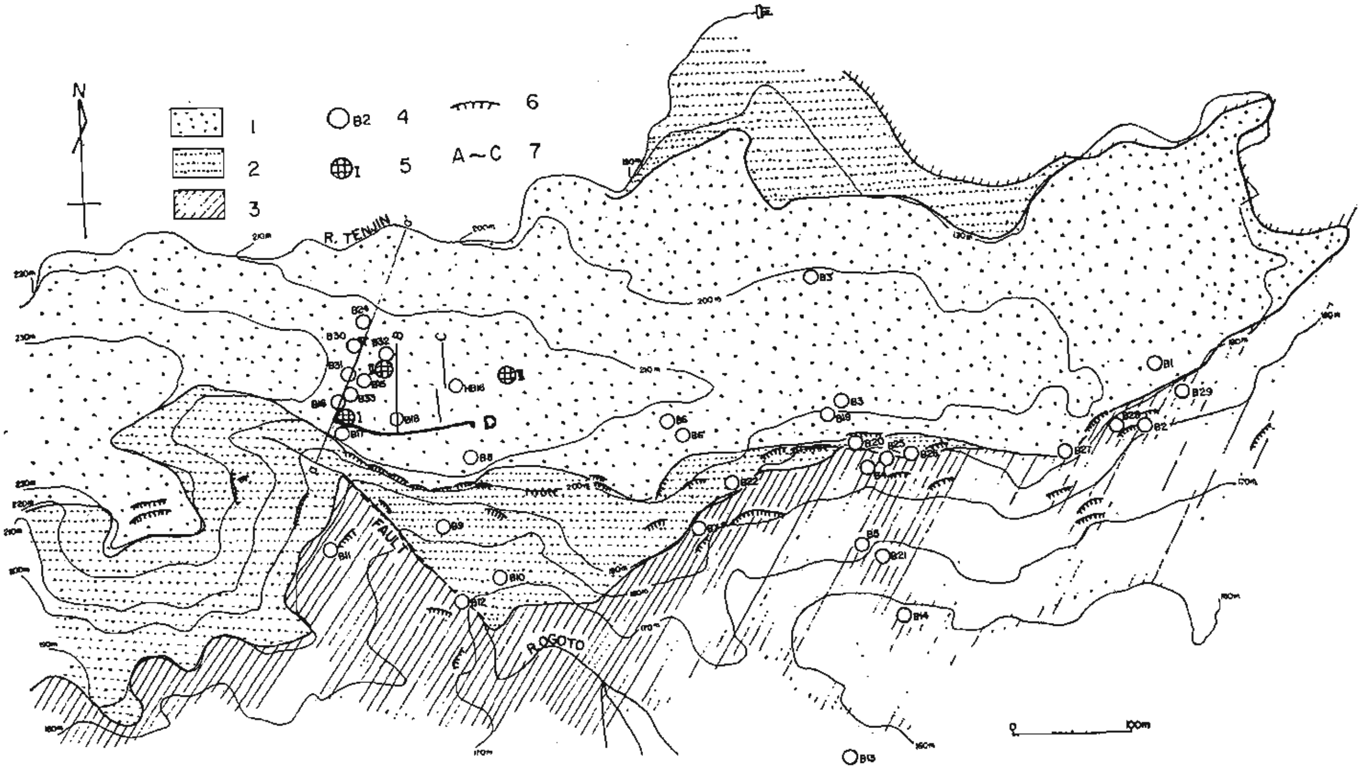

Fig. 4. (a) Geological map of Kamioogi landslide area.
1. Kamioogi gravel layer, 2. Upper part of Namjou cly layer, 3. Low part of Namjou clay layer, 4. Boring hole, 5. Water collecting well, 6. Collapse type landslide area, 7. Measuring lines of underground temperature survey.

around the landslide area.

4.2. Try of the investigation of the underground water vein-stream by the underground temperature survey

For the purpose of trying the underground temperature survey for the vein-stream investigation, this survey was conducted in a place having a simple underground structure, simple configuration and the same ground surface condition. The place is the Kamioogi landslide area in Shiga Prefecture.

This landslide area is located at the edge of the Kamioogi Hill about 200 meters above sealevel. In order to clarify a cause of this landslide, the Disaster Prevention Research Institute of Kyoto University conducted landslide investigations in and around this landslide area and these results were published.[11),12)]

The geology of this landslide area consists of the Namjou clay layer and the Kamioogi gravel layer covering the former layer. The former layer is a part of the Ko-Biwako formation and is a good impermeable layer. The upper layer consists of many gravels of sandstone, chert, granite and clay slate and is a good permeable layer. The underground water exists mainly in this layer. The head scarp of landslide exists at the boundary between the Namjou clay layer and the Kamioogi gravel layer. The underground water flowing in this layer was presumed to flow in from the Hiei Mountains, so the underground water investigations were conducted mainly at western area of the Kamioogi Hill. Because the underground water is excluded at the entrance of the channel of vein-stream, an inflow of the underground water into this landslide area is obstructed. (Fig. 4 (a) and (b))

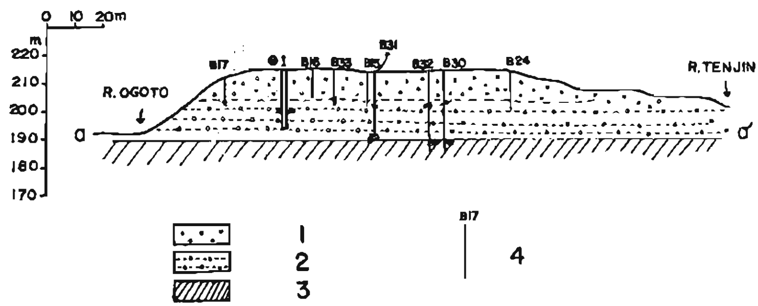

Fig. 4. (b) Geological map of Kamioogi landslide area.
1. Kamioogi gravel layer, 2. Upper part of Namjou clay layer, 3. Lower part of Namjou clay layer, 4. Boring hole,

Next underground water investigations were conducted and some informations related to the underground water were obtained, e. g. tracer method, observation of underground water level, pumping test etc.. From the results of these investigations, it became clear that the underground water existed mainly in the gravel layer and it flowed in an easterly direction of the Kamioogi settlement and to the south-east slope of the settlement. On the basis of the results, the authorities constructed two water collecting wells in the western part of the settlement. (Fig. 5) But the wells could not exclude only a small quantity in comparison with a planned quantity of water. Thus in order to catch the main channel of the vien-stream, the underground

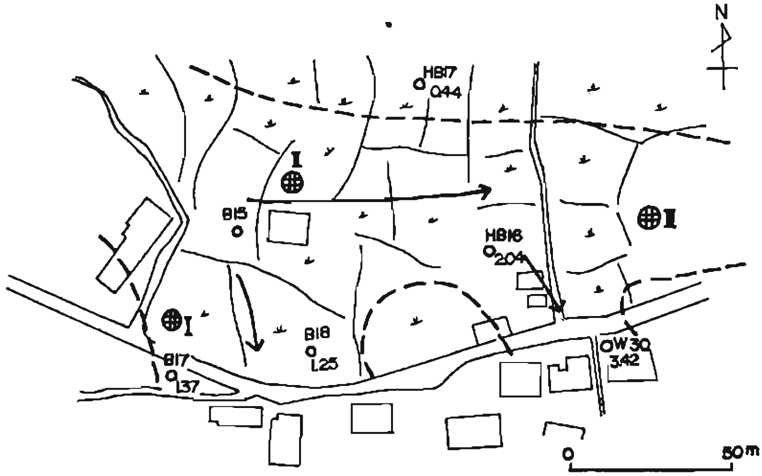

Fig. 5. Results of underground water investigations. B_{15} is a throwing point of NaCl. Numbers are velocity of underground water (unit=cm/sec)

temperature survey was conducted in this area.

This landslide area has, as aforesaid, a simple geological structure and a simple configuration, and surface condition of ground is almost completely covered by rice fields in the investigating area. Accordingly it is assumed that these conditions have an uniform effect on the underground temperature of each measuring point in this area. It is a favourable condition for catching the variation of underground temperature caused by underground water vein-streams. The underground temperature survey was conducted on 26th, September, 1965.

The direction of measuring lines was decided on the basis of the existing data as shown in Fig. 6. The number of lines is four, and the interval of measuring points

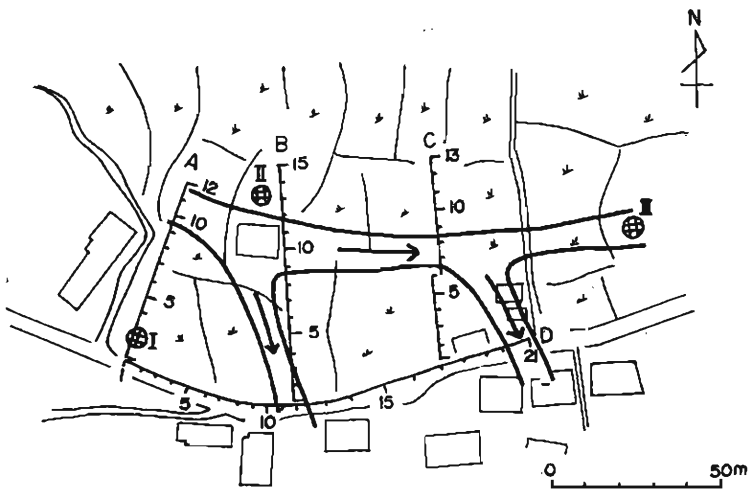

Fig. 6. Measuring lines of underground temperature survey and presumed channel of underground water vein-stream from its result.

is 5 meters. Total number of points are 60. The items in each ground surface condition is 9 points in a path and 51 points in a foot-path between rice fields.

Measuring method of temperature is as follow: Making a hole in the ground of one meter depth and 25 mm in diameter by using an iron bar, and a thermistor is inserted into the hole. (Fig. 7) After five or ten minutes, the thermistor is read and the value is regarded as the underground temperature at one meter depth of the measuring point.

Fig. 7. Senser of thermistor. (unit=m/m)

From the results of analysis of the data obtained by the above-method in each ground surface condition, the difference of temperature in each condition compared with the total average of underground temperature is 0.03°C–0.00°C. As this difference is

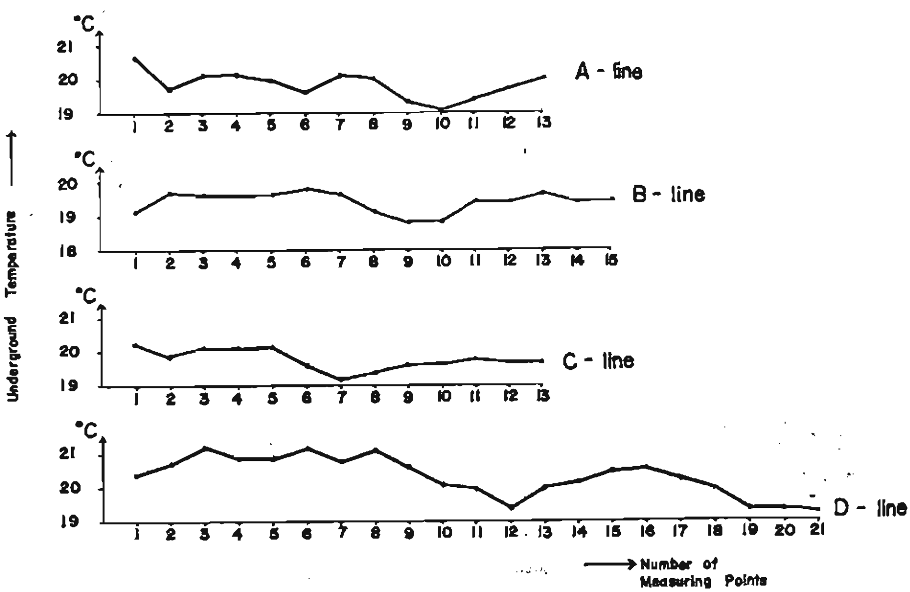

Fig. 8. Results of the measuring of underground temperature.

very small, it can not be measured by the thermistor. So at this time the temperature variation caused by ground surface condition was neglected, and the data were treated. The results are shown in Fig. 8. What is evident is that low temperature part exists in each line. These low temperature areas do not originate, as mentioned above, from the effects of geological and topographical difference, diurnal variation of underground temperature and difference of ground surface condition.

By the results of the underground temperature measurement, total average of the temperature is 19.88°C and temperature of spring point gushing out in this area is 15.35°C. The water temperature is very low compared to the underground temperature. Accordingly if this cool water flows, taking heat away from the ground surface at the same time, it is presumed that the temperature of place of the cool vein-stream is low in comparison with that of other places. If the low temperature part, as shown in Fig. 8, does not originate from the effects of geological and topographical differences, diurnal variation of underground temperature and difference of ground surface condition, it is considered most reasonable that it originates from the flowing of the cool vein-stream. The vein-stream obtained by connecting the low temperature part with one another is shown in Fig. 6.

The scale of the vein-stream is discussed by using the YUHARA's method.[13)*] (Fig. 9–11) The results are shown in Table–3, and Fig. 12. From the results it is presumed that there is an underground water vein-stream having the dimension of 5 meters radius in the ground to the depth of 9 or 10 meters (depth of the center of the vein-stream). This result agrees in outline with the result of the underground water investigation conducted in 1967. Of course, it is by no means assumed that the vein-stream with a radius of 5 meters exists in the presumed place and that water flows with a rush in the vein-stream. But at least it is suggested that the underground water having a higher velocity than the other flows converging upon the place obtained by calculation in the gravel layer exists. Accordingly, if a water collecting well is constructed at the place of the presumed vein-stream, it can be expected that a

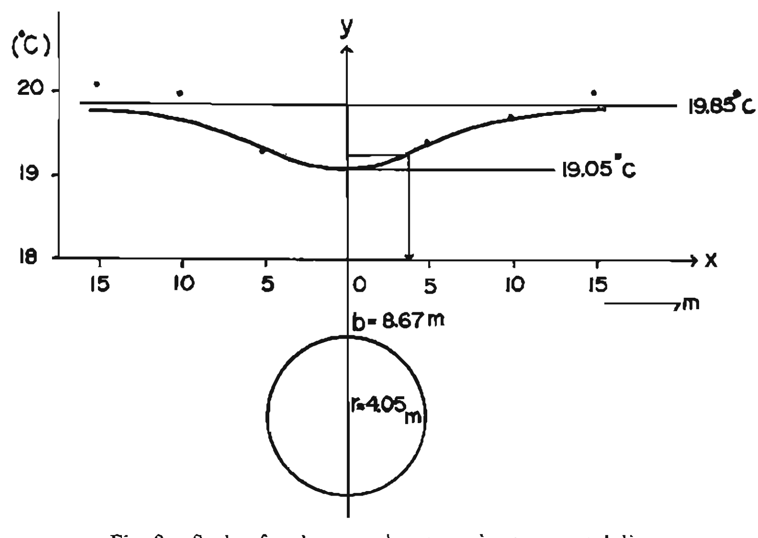

Fig. 9. Scale of underground water vein-stream at A line.

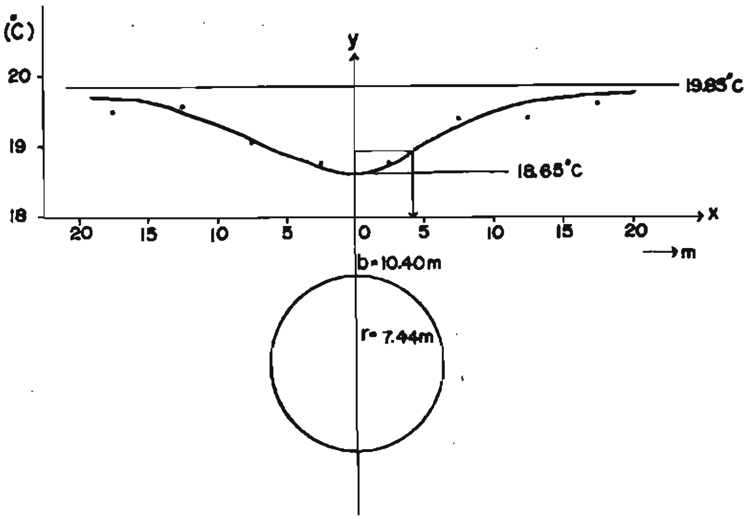

Fig. 10. Scale of underground water vein-stream at B line.

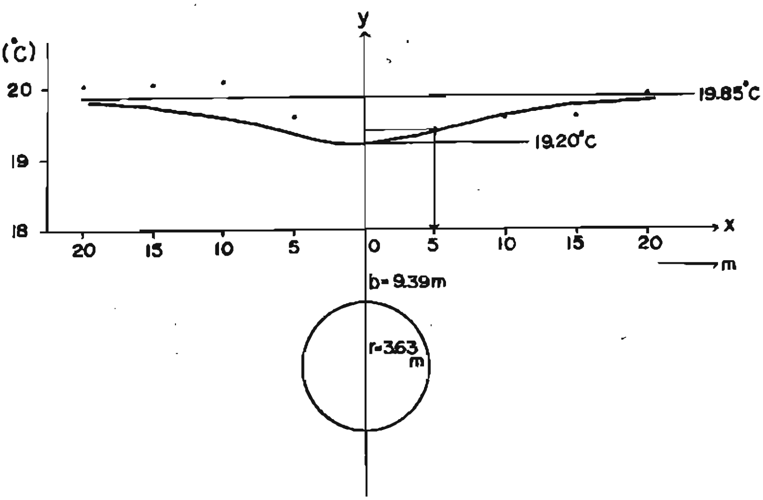

Fig. 11 Scale of underground water vein-stream at C line.

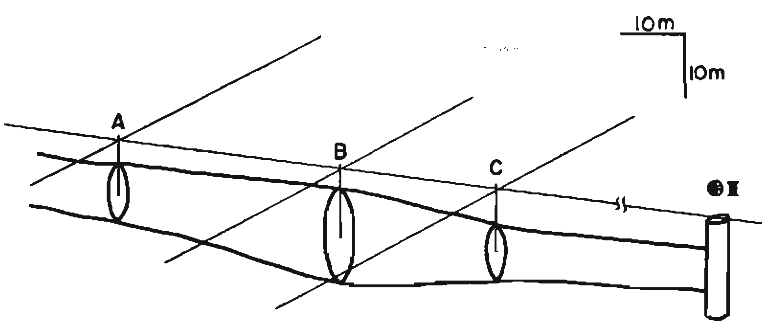

Fig. 12. Existent condition of the vein-stream by calculation.

Table 3. Calculated values of underground water vein-streams by Yuhara's method.

	Tmin.(°C)	$\overline{T}$av.(°C)	d (m)	r (m)
A–Line	19.05	19.88	8.67	4.05
B–Line	18.65	19.88	10.40	7.44
C–Line	19.20	19.88	9.39	3.63
A–Line ※$_1$	19.70	19.88	2.60	0.50
B–Line ※$_2$	19.10	19.88	4.46	1.00

Tmin. : the minumum temperature (°C)
$\overline{T}$av. : the mean temperature (°C)
d : depth of the central point of the vein-stream (m)
r : radius of the vein-stream (m)

larger quantity of water should be able to be drained. On the basis of this result, a water collecting well, which was 3 meters in diameter and 15 meters depth, was constructed at the place shown in Fig. 6 and 12. The result was that a large quantity of water was drained between 3.5 meters and 13 meters in depth. This quantity (51 l/min. in March 1969) is more than the quantity of two water collecting wells (total quantity was 35.4 l/min. in March 1969). The dimensions of vein-streams flowing into two water collecting wells are, by Table–3, about one meter in diamter. These dimensions are rather smaller than the former. A large quantity of water was drained from one of three wells, nevertheless three wells were constructed in the same permeable layer. We would like to take notice of it as the proof that there is a place where the underground water flows concentrically even in the same permeable layer.

Considering this fact, it seems that the underground water vein-stream investigating method by the temperature survey becomes one of the favorable methods for vein-stream investigation.

5. Conclusion

From discussions of the existing condition of underground water in and around a landslide area, it was suggested strongly that the underground water connecting with landslide activity existed as vein-stream form rather than as stratiform in the landslide area. If the underground water exists as vein-stream form in the landslide area, a satisfactory result is not likely to be obtained by using the existing tracer method. So it is considered a good method if we presume the existing place of the vein-stream by some other method before conducting the costly tracer method and we then conduct the tracer method to obtain its precious data only for the confirmation of the vein-stream. As one of the favorable methods of the vein-stream investigation, the underground temperature survey was conducted in the Kamioogi landslide area. From the result, this survey showed a large possibility for obtaining useful data concerning the vein-stream. The merits of the survey were as follows: The survey could be done within a short period by relatively simple methods and at small expense. These merits are important considerations for preparatory investigation.

In the future, the author intends to study the factors controlling the underground temperature beside the underground water, a way of eliminating this factor and a method for approximating the dimensions of the vein-stream.

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* It is necessary to discuss wheather or not the method is able to adapt to the presumption of the dimension of vein-streams by the underground temperature survey. At this time this method is used for obtaining the criterion in outline.

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